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Influence of hairy vetch residue on atrazine and metolachlor soil solution concentration and weed emergence

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High levels of cover-crop residue can suppress weed emergence and also can intercept preemergence herbicides and potentially reduce their effectiveness. This research was conducted in continuous no-tillage corn to compare the effect of residue from a hairy vetch cover crop with that of background crop residue on the soil solution concentration of atrazine and metolachlor and on the emergence of weeds with and without herbicide treatment. In a 3-yr field experiment, 5-cm-deep soil samples were taken and the weed density measured in paired microplots with and without herbicide at approximately weekly intervals after application of atrazine and metolachlor. High levels of residue were present in both treatments; the percentage of soil covered by residue ranged from 91 to 99 in the no–cover-crop treatment and from 99 to 100 in the hairy vetch treatment. Initial metolachlor concentration was lower and degradation rate higher in two of the 3 yr with a hairy vetch cover crop than without a cover crop. Cover-crop treatment had little effect on atrazine concentration or degradation. Annual grass weeds (predominantly fall panicum) were the major species in this field. Hairy vetch alone reduced grass emergence by 50 to 90%, and preemergence herbicides alone reduced emergence by 72 to 93% compared with the treatment without cover crop and herbicide. The combination of preemergence herbicides with hairy vetch provided only 24 to 61% control of grass weeds compared with control by hairy vetch alone and 23 to 52% compared with control by herbicide alone, suggesting an antagonism probably resulting from reduced metolachlor concentration by hairy vetch residue. Metolachlor with hairy vetch delayed emergence of weeds and reduced the concentration of metolachlor required to prevent emergence initiation compared with metolachlor without a cover crop.

Nomenclature: Atrazine; metolachlor; fall panicum, *Panicum dichotomiflorum* Michx. PANDI; corn, *Zea mays* L.; hairy vetch, *Vicia villosa* Roth VICVI.

Key words: Crop residue, cover crop, soil solution, herbicide degradation.

Crop and cover-crop residue on the surface of soils in reduced-tillage production systems can have a significant effect on the behavior of herbicides. This subject has been reviewed comprehensively by Locke and Bryson (1997). One of the primary effects of surface residue is interception of herbicides, resulting in less herbicide reaching the soil. Atrazine retention by crop residue was shown to be 56 to 70% by Isensee and Sadeghi (1994) and 61% by Ghadiri et al. (1984). Retention of acetamide herbicides was influenced by the quantity of wheat (*Triticum aestivum* L.) residue present; high residue levels intercepted greater than 80% of metolachlor (Crutchfield et al. 1986) and greater than 90% of metolachlor, acetochlor, or alachlor (Banks and Robinson 1986).

Herbicide that is intercepted by surface residue can be lost through several mechanisms, including washoff by rainfall, biodegradation, and volatilization (Locke and Bryson 1997). Approximately 73 to 96% of intercepted atrazine was lost from residue within 1 to 3 wk depending on rainfall intensity (Ghadiri et al. 1984; Isensee and Sadeghi 1994). Atrazine in leachate from various residues increased with increased levels of simulated rainfall (Isensee et al. 1998), suggesting that rainfall is an important factor in atrazine loss from residues. Increased amounts of sprinkler irrigation increased the amount of acetochlor, alachlor, and metolachlor reaching the soil surface by approximately 10 to 20% (Banks and Robinson 1986), further supporting the importance of rainfall in removing herbicide from plant residue.

Most research has focused on total herbicide concentration in soils, whereas relatively little research has been conducted to measure actual soil solution concentration. Weeds probably respond primarily to herbicide concentration in the soil solution and are particularly sensitive to factors that influence solution concentration, such as crop residues and organic matter. Shelton et al. (1995) investigated the effect of corn stalk additions on atrazine K_d values and soil solution concentration. They observed that addition of 10% corn stalk residue to soil containing 7 $\mu g\ g^{-1}$ atrazine increased K_d values from 0.63 to 3.34, whereas soil solution concentrations decreased from 8.4 to 1.5 $\mu g\ ml^{-1}$. These data indicate that weed populations are more likely to flourish in soils with high residue and organic matter levels where herbicide soil solution concentration is decreased.

Crop residue also can directly influence weed emergence. Increased quantities of crop residue reduced emergence of various weed species (Buhler et al. 1996; Crutchfield et al. 1986; Vidal and Bauman 1996). Similarly, increased levels of residue of the winter annual cover crops hairy vetch and rye (*Secale cereale* L.) also progressively reduced weed emergence (Mohler and Teasdale 1993). Teasdale and Mohler

(2000) identified two important physical properties of mulches, mulch area index and solid volume fraction, that are highly correlated with suppression of weed emergence. Teasdale (1998) and Nagabhushana et al. (2001) have reviewed many of the factors influencing weed suppression by cover crops and the role of cover crops in sustainable cropping systems. One general conclusion is that natural quantities of crop or cover-crop residue can suppress emergence of weeds early in the season but are not sufficient to provide full-season weed control; herbicides or alternative control practices should be integrated with cover crops to achieve successful weed control programs.

Despite the potential importance of herbicides in cover-crop–based systems, there has been negligible research investigating the effect of cover crops on herbicide behavior and weed emergence. Although high levels of cover-crop residue may be desirable for direct suppression of weed emergence, high residue levels also can intercept herbicides and potentially reduce the effectiveness of soil-active herbicides. Crutchfield et al. (1986) showed that increased biomass of wheat residue increased weed suppression and decreased soil metolachlor concentrations, but reduced herbicide concentrations did not reduce overall weed control. Additional research is needed to understand the interactions among cover-crop residue, herbicide behavior, and weed emergence. We chose to focus on hairy vetch, which has become a popular cover crop for corn production in the mid-Atlantic states, and on atrazine and metolachlor, which are widely used herbicides for corn. This research was conducted to compare the effect of residues of a hairy vetch cover crop with that of background crop residue in no-tillage corn production on (1) soil solution concentrations of atrazine and metolachlor and (2) the emergence of weeds with and without herbicide treatment.

Materials and Methods

Experiments were conducted on the South Farm of the Beltsville Agricultural Research Center, Beltsville, MD, in 1997, 1998, and 1999. The site was located in the coastal plain of Maryland and consisted of a mixture of Matapeake (fine-silty, mixed, semiactive, mesic Typic Hapludults)–Muirkirk (clayey, kaolinitic, mesic Arenic Paleudults) complex and Matawan (fine-loamy, siliceous, semiactive, mesic Aquic Hapludults)–Hammonton (coarse-loamy, siliceous, semiactive, mesic Aquic Hapludults) loamy sands with 2.4% organic matter in the surface 5 cm of soil. Eight watersheds ranging from 0.10 to 0.23 ha (labeled A to H) were established in this field by installing earthen berms in 1995 for research on herbicide movement in ground and surface water. All watersheds were not tilled after the spring of 1995. In the falls before the 1997 to 1999 seasons, 28 kg ha^{-1} of hairy vetch seeds were planted in watersheds B, C, F, and G, whereas watersheds A, D, E, and H received no cover crop. Paraquat was applied at 0.56 kg ai ha^{-1} to kill all live vegetation, and fertilizer was broadcast at recommended rates to the entire field shortly before planting in spring. Corn was planted without tillage on May 20, 17, and 25 of 1997, 1998, and 1999, respectively. This established two soil residue treatments: (1) a standard no-tillage system with residues of winter weeds plus corn stalks and (2) a no-tillage hairy vetch system with residues of a hairy vetch cover crop plus corn stalks.

Plastic tarps (1.7 by 2.3 m) were installed to cover the soil at four random locations in each watershed. These sites were in different locations in each year. A tank mixture of atrazine plus metolachlor at 1.8 plus 2.2 kg ai ha^{-1} was applied preemergence to the entire field on May 28, 19, and 26 of 1997, 1998, and 1999, respectively. After the tarps were removed, metal frames, 1.2 by 1.2 m on a side by 10 cm high, were pressed 5 cm into the untreated soil to prevent herbicide runoff across the area within the frame. This established two herbicide treatments in each watershed: (1) the majority of soil that was treated with the atrazine and metolachlor and (2) four microplots that were not treated with herbicides.

Three soil cores, each 1.9 cm in diameter and 5 cm deep, were removed from herbicide-treated soil at approximately weekly intervals beginning shortly after preemergence herbicide application and continuing until corn canopy closure. Sampling was limited to 5-cm depth, which is the depth from which most weeds are expected to emerge. At each sampling date, cores were taken from sites surrounding each microplot. The cores associated with each date and microplot were combined and mixed in a glass jar. The soil solution concentrations of atrazine and metolachlor were determined according to methods described by Shelton et al. (1998). Briefly, samples were refrigerated, and within 24 h, 1 to 2 ml of soil water was pressed from a 25-g subsample using hydraulic pressure (Shelton and Parkin 1991). Water samples were frozen until they were vortex extracted with ethyl acetate. The ethyl acetate was dried with sodium sulfate and analyzed for herbicides by gas chromatography using a nitrogen–phosphorus detector. The gas chromatograph was fitted with a 1-m guard column connected to a capillary column, of 30-m height and 0.25-mm inside diameter, phase coated with 0.25 μm 100% dimethylpolysiloxane. The helium carrier flow was 1 ml min^{-1} at 140 C. The injector temperature was 220 C, and the detector temperature was 280 C. Samples were injected in the splitless mode, and the oven was multilevel temperature programmed as follows: 70 C, ramped at 15 C min^{-1} to 160 C and held for 3 min, ramped at 1 C min^{-1} to 169 C, and ramped at 15 C min^{-1} to 265 C and held for 3 min. The average atrazine extraction efficiency was 70% with a standard deviation of 6%, whereas the average metolachlor extraction efficiency was 107% with a standard deviation of 8%. Values obtained for atrazine were corrected to account for lost efficiency, whereas metolachlor values were left uncorrected.

Weed density in each microplot was determined within 1 d of each soil sampling date from the beginning of weed emergence until corn canopy closure. The number of weeds by species in three 0.1-m^2 frames located between corn rows was counted both within each microplot (herbicide-free site) and next to each coring site (herbicide-treated site). Residue cover also was determined at each weed density site by placing a 0.5-m^2 clear plexiglass sheet with a 100-dot grid over the site and by counting the number of dots with residue directly underneath.

Analysis of variance was conducted on herbicide concentration and weed density data after log transformation to homogenize variance. A mixed model procedure was used with cover crop, time after application, and herbicide as fixed effects and block as a random effect. Means were back-

TABLE 1. Residue cover 20, 8, and 14 d after herbicide application in 1997, 1998, and 1999, respectively, for no-tillage continuous corn (*Zea mays* L.) with and without a hairy vetch (*Vicia villosa* Roth) cover crop.[a]

Cover crop[a]	Residue cover[b] 1997	1998	1999
	%		
None	90.9 (1.3)	96.1 (1.2)	98.9 (0.3)
Hairy vetch	98.8 (0.3)	99.4 (0.2)	99.8 (0.2)

[a] Residue in the no–cover-crop treatment consisted of corn stalks plus winter annual weeds. Residue in the hairy vetch treatment consisted of corn stalks plus hairy vetch.

[b] Percentage of soil area covered by residue. Standard error of the mean is presented in parentheses.

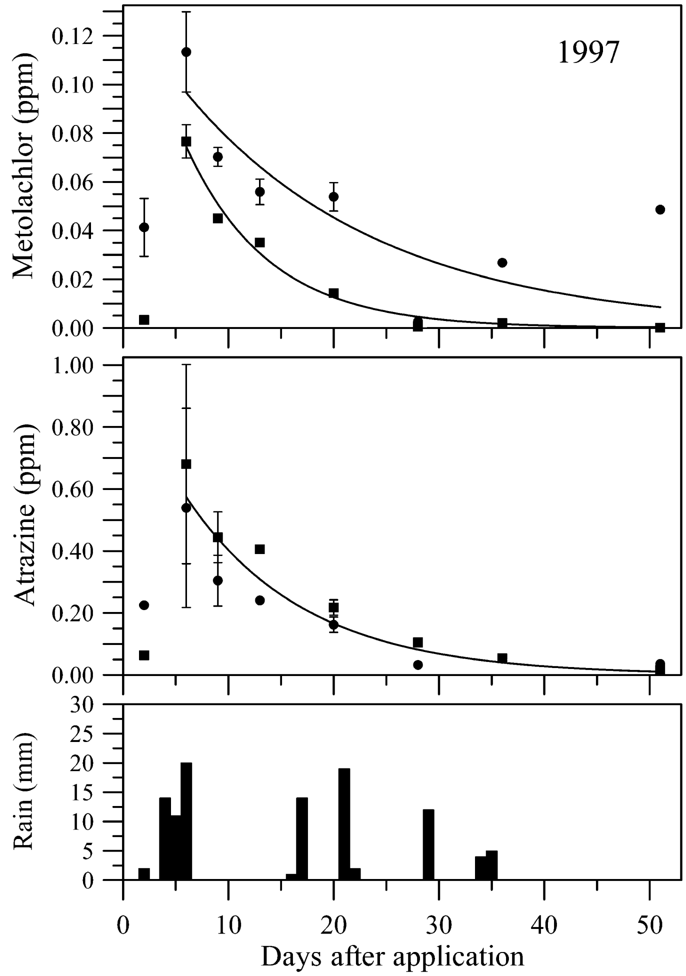

FIGURE 1. Atrazine and metolachlor soil solution concentration in the upper 5 cm of soil and rainfall for no-tillage continuous corn (*Zea mays* L.) with (■) or without (●) a hairy vetch (*Vicia villosa* Roth) cover crop in 1997. Error bars indicate the standard error of the mean. Symbols without error bars indicate that the standard error was not greater than the width of the symbol. Regression coefficients are presented in Table 3.

transformed for presentation. Herbicide degradation was determined using the first-order rate model $\ln C = \ln C_0 - kt$, where C is the soil solution concentration after time t, C_0 is the initial concentration, and k is a rate constant (Walker 1987). Accordingly, log-transformed herbicide concentration data were subjected to analysis of covariance with cover crop as a class variable and time after application as a first-order linear regression variable to test for the significance of herbicide degradation and interactions between degradation rate and cover-crop treatment. The Gompertz function (Forcella et al. 2000) was fit to back-transformed weed emergence means as a function of time, excluding data where obvious self-thinning occurred near the time of canopy closure. The inflection point of this function (defined as the time when weed emergence equaled 0.14 of the maximum value) provided a useful measure of the beginning of emergence.

Results and Discussion

At least 90% of soil was covered by residue in the spring of all years (Table 1). The field had not been tilled since 1995, resulting in accumulation of corn residue. In addition, winter annual weeds, primarily common chickweed [*Stellaria media* (L.) Vill.] and annual bluegrass (*Poa annua* L.), accumulated each spring in the treatment without cover crop. Soil cover where no cover crop was used increased each year from 90.9% in 1997 to 98.9% in 1999. Soil cover was greater than 98% in the hairy vetch watersheds in each year.

Because of the need for repeated sampling of weed populations in each microplot, a nondestructive measure of residue quantity such as soil cover was required rather than a destructive measure such as mass. However, using quantitative relationships described by Teasdale and Mohler (2000), it was possible to estimate the mass of residue in these experiments. For example, percent soil cover values of 98.8 and 90.9 for treatments with and without hairy vetch in 1997 corresponded to mass values of 850 and 545 g m^{-2}, respectively. Thus, a 9% difference in cover between watersheds with and without hairy vetch corresponded to a 56% difference in mass. Mulch area index, defined as the area of mulch elements per soil area, is a property that is highly correlated with weed suppression (Teasdale and Mohler 2000) and could be equally important to herbicide interception. In 1997, estimated mulch area index values for treatments with and without hairy vetch were 4.4 and 2.4, respectively, representing an 84% difference between these treatments. Although differences in residue cover between cover-crop treatments were small, these differences represented relatively larger differences in mass and mulch area index between treatments. This is because when distribution of mulch elements is assumed to be random, increasingly more mulch is required to attain each successive increment in soil coverage.

Herbicide Concentration

Herbicide soil solution concentrations in no-tillage systems are expected to be less than those under tillage conditions. Shelton et al. (1998) showed that atrazine soil solution concentrations in these fields when plowed averaged approximately 5 $\mu g\ ml^{-1}$ in the surface 5 cm, whereas atrazine concentrations without tillage and without crop residue averaged approximately 2 $\mu g\ ml^{-1}$. In our experiments (Figures 1–3), high levels of surface residue in all years and lack of timely rainfall in 1998 and 1999 probably accounted for the low initial concentrations of both atrazine (0.06 to 0.57 $\mu g\ ml^{-1}$) and metolachlor (0.02 to 0.10 $\mu g\ ml^{-1}$).

The initial concentrations of metolachlor and atrazine in

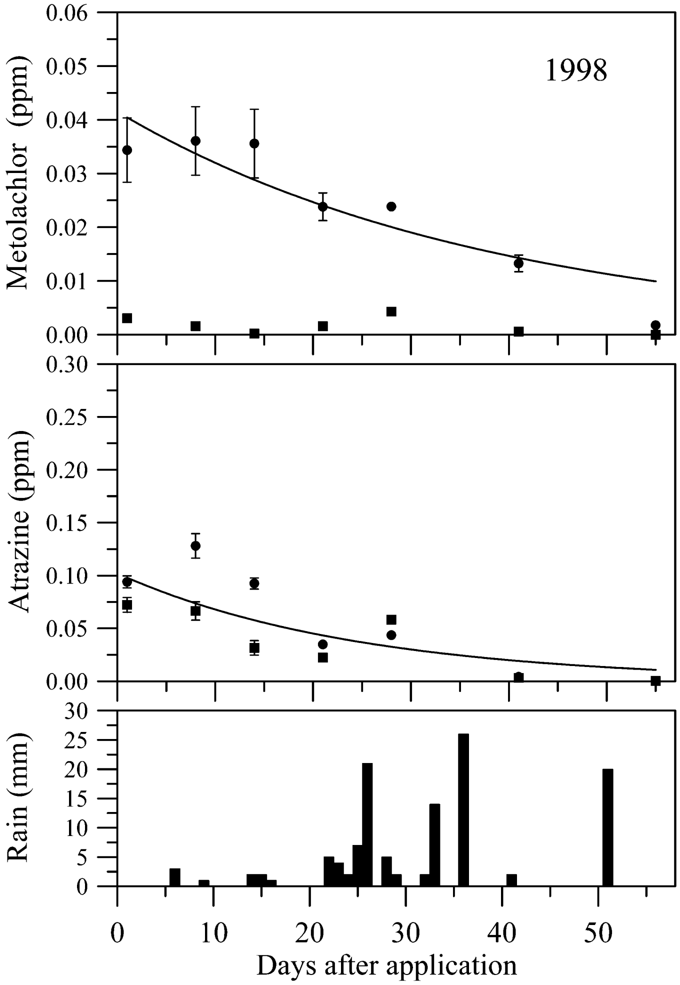

FIGURE 2. Atrazine and metolachlor soil solution concentration in the upper 5 cm of soil and rainfall for no-tillage continuous corn (*Zea mays* L.) with (■) or without (●) a hairy vetch (*Vicia villosa* Roth) cover crop in 1998. Error bars indicate the standard error of the mean. Symbols without error bars indicate that the standard error was not greater than the width of the symbol. Regression coefficients are presented in Table 3.

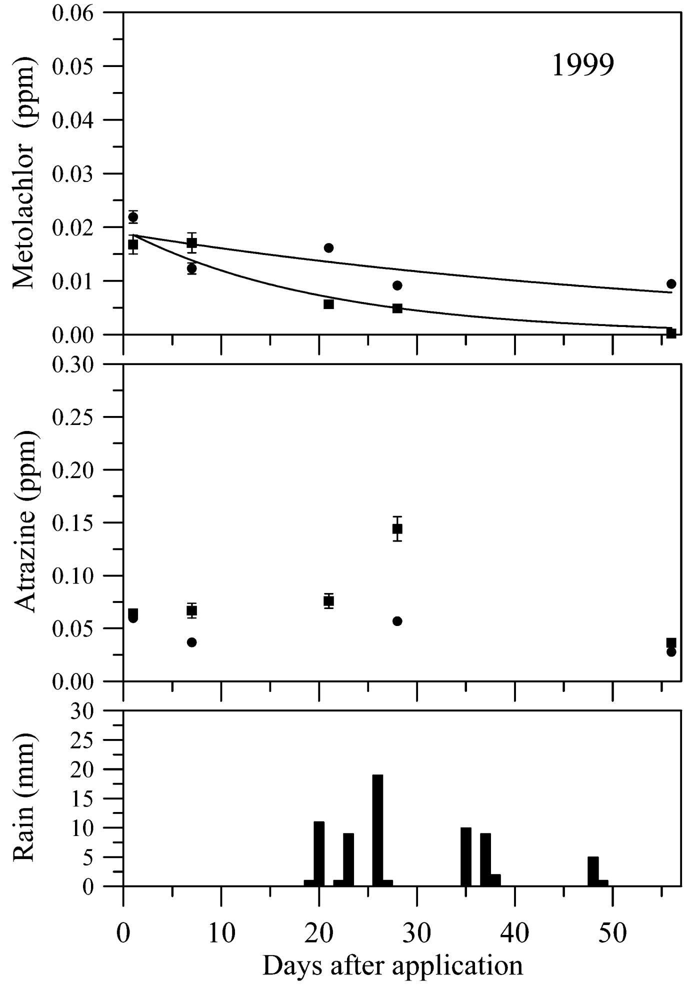

FIGURE 3. Atrazine and metolachlor soil solution concentration in the upper 5 cm of soil and rainfall for no-tillage continuous corn (*Zea mays* L.) with (■) or without (●) a hairy vetch (*Vicia villosa* Roth) cover crop in 1999. Error bars indicate the standard error of the mean. Symbols without error bars indicate that the standard error was not greater than the width of the symbol. Regression coefficients are presented in Table 3.

the soil solution 2 d after application in 1997 were lower in watersheds with hairy vetch cover-crop than in those without it (Figure 1). Rain during Days 4 through 6 after application in 1997 was associated with an increase in soil solution concentration of both herbicides 6 d after application. Because concentration of both herbicides declined after 6 d of application, analysis of covariance with a first-order decay model was performed with data beginning on Day 6. This analysis showed a significant cover-crop by time interaction for metolachlor in 1997 (Table 2), signifying a different rate of herbicide loss in each cover-crop treatment. The rate of metolachlor decline was faster with a hairy vetch cover crop than without it, as indicated by a half-life of 11.5 d with hairy vetch compared with that of 18.8 d without hairy vetch (Table 3).

A spike in metolachlor soil solution concentration did not occur in 1998 and 1999 as it did in 1997, probably because of minimal rainfall during the first 20 d of application in both years (Figures 1 to 3). Consequently, analysis of covariance was conducted on all data in these years. There was a significant cover-crop effect on metolachlor concentration in 1998 (Table 2); initial metolachlor concentration was an order of magnitude lower in watersheds with hairy vetch than in those without hairy vetch (Figure 2). The lack of a significant interaction between cover crop and time in 1998 was probably the result of such low initial metolachlor concentrations in hairy vetch that a significant regression could not be established for this treatment (Table 3). In 1999, as in 1997, there was a significant cover-crop by time interaction for metolachlor concentration (Table 2), in which metolachlor disappeared faster with hairy vetch than without it (Table 3). Because there were no differences in runoff from these watersheds with or without hairy vetch (Sadeghi and Isensee 2001), the faster disappearance of metolachlor from soils with a hairy vetch cover crop probably was due to faster degradation.

In 1997 and 1998, initially lower metolachlor soil solution concentrations with hairy vetch than without it corresponded to higher residue levels in hairy vetch in those years (Table 1). Similar initial metolachlor concentrations in cover-crop treatments in 1999 were associated with similarly high residue cover for both treatments (Table 1). These results agree with previous research that showed that a high proportion of metolachlor can be intercepted by plant res-

TABLE 2. Analysis of covariance of metolachlor and atrazine soil solution concentration with cover-crop treatment as a class variable and time after application as a regression variable.

Herbicide	Source	P > F[a] 1997	1998	1999
Metolachlor	Cover crop	0.9233	0.0001**	0.2366
	Time	0.0001**	0.0001**	0.0001**
	Cover crop × time	0.0119*	0.7749	0.0001**
Atrazine	Cover crop	0.1110	0.0576	0.2095
	Time	0.0001**	0.0001**	0.0813
	Cover crop × time	0.8308	0.1133	0.6686

[a] * and ** indicate significance at $P < 0.05$ and 0.01, respectively.

idue and retained after rainfall (Banks and Robinson 1986). On the other hand, atrazine was less affected by cover crop than was metolachlor; initial atrazine concentration was reduced by hairy vetch only in 1997, and analysis of covariance showed no significant effects or interactions involving cover-crop treatment in any year (Table 2). Previous research suggests lower retention of atrazine by residue and greater release by rainfall (Ghadiri et al. 1984; Isensee and Sadeghi 1994) than has been observed for metolachlor (Banks and Robinson 1986; Crutchfield et al. 1986). This may account for why the cover crop influenced atrazine less than metolachlor.

Weed Populations

Annual grass weeds accounted for 88% of the total number of weeds that emerged in 1997 and 1998 and 72% of the weeds that emerged in 1999. The predominant annual grass species was fall panicum (data not shown). Almost all two- and three-factor interactions among cover crop, herbicide, and time of sampling were significant for grass populations in each year (data not shown). Smooth pigweed (*Amaranthus hybridus* L.) also was present in 1997 in sufficient numbers to show significant treatment effects (data not shown).

Annual grass density was highest in the no–cover-crop treatment without herbicide in all years (Figure 4). Grass numbers peaked at 191, 77, and 46 plants m^{-2} in 1997, 1998, and 1999, respectively, in this treatment, based on the *A* coefficient in the fitted Gompertz models (Table 4). Self-thinning due to intraspecific competition probably accounted for the reduction in numbers that occurred in this treatment after maximum emergence in 1997 and 1998 (Figure 4). Progressively lower rainfall from 1997 to 1999 may account for the progressive reduction in maximum emergence across these years.

Hairy vetch residue without herbicide reduced maximum emergence by 90, 82, and 50% in 1997, 1998, and 1999, respectively, compared with the no–cover-crop treatment without herbicide (computed from the *A* coefficients in Table 4). Given the high degree of soil cover by residue in all treatments (Table 1), this degree of suppression may seem unusually high. Both treatments had similar amounts of underlying corn residue. However, hairy vetch probably had more suppressive capability than did the relatively friable and fragile winter-weed residue in the treatment without cover crop.

The preemergence herbicide mixture of atrazine plus metolachlor without a cover crop reduced maximum grass emergence by 93, 72, and 72% in 1997, 1998, and 1999, respectively, compared with the no–cover-crop treatment without herbicide (Table 4). Metolachlor was probably responsible for control of grass weeds because fall panicum was the major grass species and metolachlor, and not atrazine, is labeled for control of this species. Preemergence herbicides with the hairy vetch treatment reduced maximum grass emergence by 96, 86, and 78% in 1997, 1998, and 1999, respectively, compared with the no–cover-crop treatment without herbicide (Table 4). However, most of this control could be accounted for by the hairy vetch cover crop alone. Herbicide applied with hairy vetch provided only 24, 56, and 61% additional control of grass emergence in 1997, 1998, and 1999, respectively, when compared with hairy vetch without herbicide. This suggests an antagonism between preemergence metolachlor and hairy vetch, probably

TABLE 3. Intercept and rate coefficients for degradation of metolachlor and atrazine with or without a hairy vetch (*Vicia villosa* Roth) cover crop according to the first-order rate model $C = C_0 \exp(-kt)$ where C is soil solution concentration at time t, C_0 is initial concentration, and k is a rate coefficient.

Herbicide	Cover crop	C_0 1997	C_0 1998	C_0 1999	k 1997	k 1998	k 1999	Half-life[a] 1997	Half-life[a] 1998	Half-life[a] 1999
		ppm						d		
Metolachlor	None	0.0966	0.0415	0.0188	0.0540	0.0260	0.0156	18.8	26.7	44.4
	Hairy vetch	0.0745	0.0016	0.0195	0.1272	NS[b]	0.0489	11.5	—[c]	14.2
Atrazine	Pooled[d]	0.5736	0.1023	0.0644	0.0866	0.0407	NS	14.0	17.0	—

[a] Half-life = $0.693/k$ and is expressed as days after application. Note that the model was initiated 6 d after application in 1997, so the reported half-life is the computed half-life plus 6 d.

[b] NS indicates model not significant at $P = 0.05$. In this case, $C = C_0$ = the average value.

[c] Half-life was not computed because of nonsignificant k coefficient value.

[d] Data with and without a hairy vetch cover crop were pooled for atrazine because there were no significant cover crop effects (Table 2).

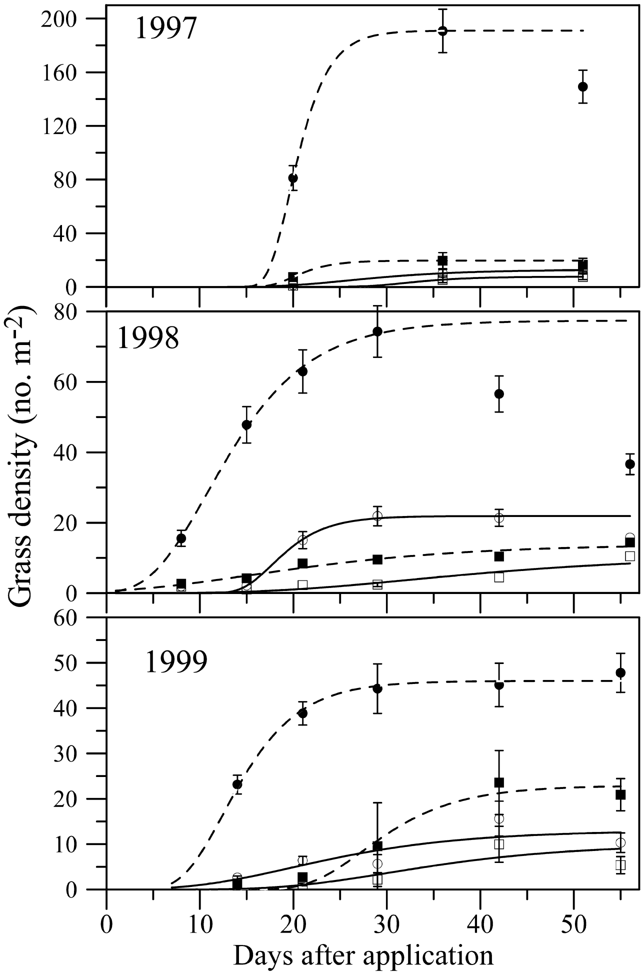

FIGURE 4. Influence of a hairy vetch (*Vicia villosa* Roth) cover crop and the herbicides atrazine plus metolachlor on density of annual grass weeds in no-tillage continuous corn (*Zea mays* L.). Treatments were no hairy vetch, no herbicide (– –●– –); no hairy vetch, plus herbicide (– –○– –); hairy vetch, no herbicide (– –■– –); and hairy vetch, plus herbicide (– –□– –) . Error bars indicate the standard error of the mean. Symbols without error bars indicate that the standard error was not greater than the width of the symbol. Gompertz model coefficients are presented in Table 4.

because soil solution concentration is reduced by hairy vetch residue.

An interesting interaction was observed for smooth pigweed in 1997. Smooth pigweed densities were less than 5 plants m^{-2} in treatments without herbicide, probably because of competition from the grass weeds established earlier. Smooth pigweed was virtually absent from the no–cover-crop treatment with herbicide. This population was triazine resistant (data not shown), suggesting that metolachlor was responsible for smooth pigweed control. However, smooth pigweed density in the hairy vetch treatment with herbicide (17 plants m^{-2}) was higher than that in the other treatments 36 d after application. This unique situation can be accounted for by a combination of factors: first, metolachlor controlled grass species sufficiently to prevent competition with smooth pigweed; second, metolachlor concentration became negligible in this treatment late in the season (Figure 1); and third, hairy vetch residue has been shown to stimulate pigweed emergence under some conditions (Teasdale and Mohler 2000).

The Gompertz function that modeled weed emergence data in these experiments is asymmetric, having an inflection point at 0.14 times the maximum value. Because of this asymmetry, the inflection point provides a convenient measure of the beginning of weed emergence. The inflection point for the no–cover-crop treatment without herbicide was 18, 7, and 10 d after application in 1997, 1998, and 1999, respectively (Table 4). Emergence may have begun later in 1997 than in subsequent years because of cooler temperatures (average air temperatures during the first 3 wk after planting were 16, 21, and 22 C in 1997, 1998, and 1999, respectively).

In 1997 and 1998, hairy vetch alone had no influence on the initiation of emergence, but preemergence herbicide delayed emergence by 3 to 9 d with no cover crop and by 11 to 14 d with hairy vetch compared with the treatment without cover crop or herbicide (Table 4). In 1999, hairy vetch alone delayed emergence by 14 d. In all years, herbicide plus hairy vetch delayed emergence by 7 to 10 d compared with herbicide alone. Where delays occurred, the competitive potential of weeds to reduce corn yields would have been reduced (Hall et al. 1992).

The predicted metolachlor soil solution concentration at the time emergence began was determined from the first-order rate equation on the day of the inflection point for weed emergence (Table 4). Accordingly, grass emergence began at metolachlor concentrations ranging from 0.015 to 0.043 $\mu g\ ml^{-1}$ without a cover crop, whereas emergence began at metolachlor concentrations ranging from 0.002 to 0.007 $\mu g\ ml^{-1}$ with a hairy vetch cover crop (Table 4). Approximately 10-fold less metolachlor was required in the soil solution to inhibit initiation of grass emergence with a hairy vetch cover crop than without it. This could be explained by an increased sensitivity to metolachlor of seedlings weakened by etiolation after traversing through a hairy vetch mulch.

A hairy vetch cover crop had both positive and negative influences on weed control by metolachlor. Hairy vetch both reduced the initial soil solution concentration and increased the rate of decomposition of metolachlor in two of the 3 yr. Consequently, preemergence application of metolachlor with a hairy vetch cover crop provided less grass control (an average of 47% grass control compared with 79% control without hairy vetch) and provided a niche for increased smooth pigweed emergence in 1 yr. However, herbicide application with hairy vetch consistently delayed grass emergence and appeared to reduce the concentration of metolachlor required to delay the initiation of grass emergence. These delays could have reduced the potential competitiveness of populations that did emerge. More research is needed to define the effect of cover-crop residue on herbicide concentration and degradation as well as the effect of herbicide activity on weed seedling emergence.

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TABLE 4. Parameters for grass emergence with or without a hairy vetch (*Vicia villosa* Roth) cover crop and plus or minus herbicide according to the Gompertz model $E = A\,(\exp(-B\,\exp(-rt)))$, where E is grass emerged per square meter, A is maximum emergence, B is an initiation coefficient, r is a rate coefficient, and t is time.

Year	Herbicide	Cover crop	A	B	r	Inflection[a]	Metolachlor concentration at inflection[b]
			no. m^{-2}			d	ppm
1997	Minus	None	191.0	18.0	0.435	18.1	—[c]
		Hairy vetch	19.6	18.4	0.420	18.3	—
	Plus	None	12.8	6.27	0.144	21.0	0.0430
		Hairy vetch	7.7	103	0.247	29.0	0.0040
1998	Minus	None	77.4	5.03	0.165	6.6	—
		Hairy vetch	13.9	2.95	0.0752	6.2	—
	Plus	None	21.9	184	0.312	15.5	0.0277
		Hairy vetch	10.5	7.89	0.0651	22.1	0.0016
1999	Minus	None	46.0	3.52	0.226	9.5	—
		Hairy vetch	22.9	36.9	0.177	23.5	—
	Plus	None	13.0	3.43	0.0968	12.6	0.0154
		Hairy vetch	10.0	8.09	0.0902	22.5	0.0065

[a] Days after application when inflection point occurred.
[b] Metolachlor soil solution concentration on day of inflection as determined from models in Table 3.
[c] No herbicide treatment.

Literature Cited

Banks, P. A. and E. L. Robinson. 1986. Soil reception and activity of acetochlor, alachlor, and metolachlor as affected by wheat straw and irrigation. Weed Sci. 34:607–611.

Buhler, D. D., T. C. Mester, and K. A. Kohler. 1996. The effect of maize residues and tillage on emergence of *Setaria faberi*, *Abutilon theophrasti*, *Amaranthus retroflexus*, and *Chenopodium album*. Weed Res. 36:153–165.

Crutchfield, D. A., G. A. Wicks, and O. C. Burnside. 1986. Effect of winter wheat straw mulch level on weed control. Weed Sci. 34:110–114.

Forcella, F., R.L.B. Arnold, R. Sanchez, and C. M. Ghersa. 2000. Modeling seedling emergence. Field Crops Res. 67:123–139.

Ghadiri, H., P. J. Shea, and G. A. Wicks. 1984. Interception and retention of atrazine by wheat stubble. Weed Sci. 32:24–27.

Hall, M. R., C. J. Swanton, and G. W. Anderson. 1992. The critical period of weed control in grain corn. Weed Sci. 40:441–447.

Isensee, A. R. and A. M. Sadeghi. 1994. Effects of tillage and rainfall on atrazine residue levels in soil. Weed Sci. 42:462–467.

Isensee, A. R., A. M. Sadeghi, and R. S. Mylavarapu. 1998. Impact of burn-down herbicides on atrazine washoff from vegetation. Chemosphere 36:13–19.

Locke, M. A. and C. T. Bryson. 1997. Herbicide-soil interactions in reduced tillage and plant residue management systems. Weed Sci. 45: 307–320.

Mohler, C. L. and J. R. Teasdale. 1993. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereale* L. residue. Weed Res. 33: 487–499.

Nagabhushana, G. G., A. D. Worsham, and J. P. Yenish. 2001. Allelopathic cover crops to reduce herbicide use in sustainable agricultural systems. Allelopathy J. 8:133–146.

Sadeghi, A. M. and A. R. Isensee. 2001. Impact of hairy vetch cover crop on herbicide transport under field and laboratory conditions. Chemosphere 44:109–118.

Shelton, D. R. and T. B. Parkin. 1991. Effect of moisture on sorption and biodegradation of carbofuran in soil. J. Agric. Food Chem. 39:2063–2068.

Shelton, D. R., A. M. Sadeghi, and A. R. Isensee. 1998. Effect of tillage on atrazine bioavailability. Soil Sci. 163:891–896.

Shelton, D. R., A. M. Sadeghi, J. S. Karns, and C. J. Hapeman. 1995. Effect of wetting and drying of soil on sorption and biodegradation of atrazine. Weed Sci. 43:298–305.

Teasdale, J. R. 1998. Cover crops, smother plants, and weed management. Pages 247–270 *in* J. L. Hatfield, D. D. Buhler, and B. A. Stewart, eds. Integrated Weed and Soil Management. Chelsea, MI: Ann Arbor Press.

Teasdale, J. R. and C. L. Mohler. 2000. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci. 48:385–392.

Vidal, R. A. and T. T. Bauman. 1996. Surface wheat (*Triticum aestivum*) residues, giant foxtail (*Setaria faberi*), and soybean (*Glycine max*) yield. Weed Sci. 44:939–943.

Walker, A. 1987. Herbicide persistence in soil. Rev. Weed Sci. 3:1–17.

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